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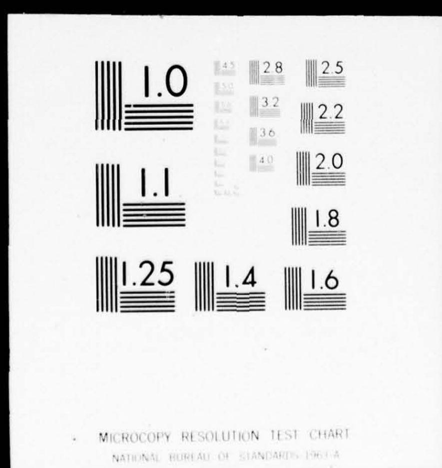
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AFCS TECHNICAL REPORT

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Microwave path testing is necessary to confirm path performance predictions, field surveys and to optimize transmission quality by determining the best antenna heights to minimize fading due to reflections. Path testing is the most accurate method for identifying path obstructions, confirming adequacy of map details and for precluding engineering errors. The objective of this report are to emphasize the importance of path testing and to provide a brief description of the path testing techniques being used today.

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1.0 INTRODUCTION

1.1 General. Reliable communications can be obtained over point-to-point radio relay systems just as they can be obtained over conventional wire and cable systems. A radio system can be made reliable by engineering the system to compensate for predictable variations in propagation losses. Very significant propagation losses can occur because of the obstruction or reflection of radio waves.

1.2 Reflections. Reflections play an important role in microwave communications. Reflections can enhance signal levels but, of more concern, they can cause severe signal degradation. Reflections can occur over almost any type of terrain but are most severe over smooth surfaces such as water or smooth earth. If both reflected and direct waves reach the receive antenna simultaneously, it is possible for the two signals to cancel each other and appreciably reduce the received signal strength. Therefore, it is of prime importance to determine the exact locations of reflection points and the severity of the reflections. With this information, the engineer can optimize the height of the antennas to avoid this type of signal degradation. Path testing provides a means for making this determination.

1.3 Obstructions. Obstructions, or blocking of the microwave beam, can also reduce the received signal level. Antenna heights can be chosen so that the microwave beam will not be obstructed, however, excessive tower heights are costly and can introduce additional problems. To ensure that new towers will be built only as high as necessary, the location and height of path obstructions must be known. This information can be obtained by path testing.

1.4 Techniques. Present day path testing is done almost entirely by the continuous wave (CW) method. An alternate method making use of a digital bit stream has also been in use recently.

1.5 Objective. The objectives of this report are to emphasize the importance of path testing and to provide a brief description of the path testing techniques being used today.

2.0 FADING

2.1 Reflection. Fading due to reflection, as depicted in Figure 1, is a function of the reflection coefficient of the reflecting surface and the phase of the reflected signal. Furthermore, the phase of the reflected signal is a function of path clearance and can be explained by the Fresnel zone concept.

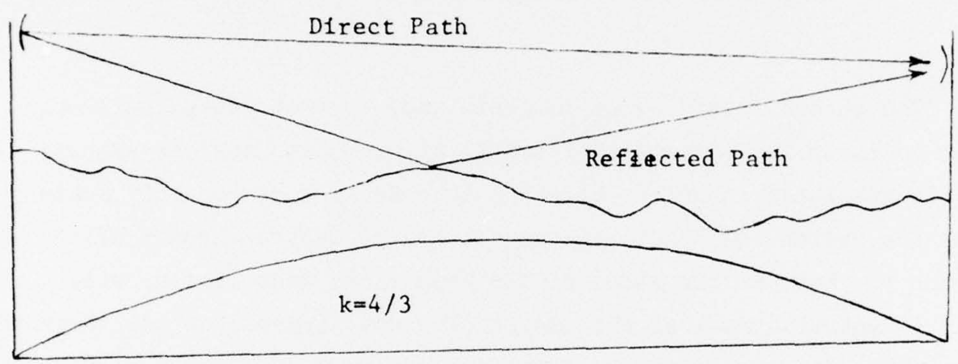


Figure 1. Reflective Path

2.1.1 Fresnel Zones. Fresnel zones can be thought of as imaginary ellipsoids drawn around the main signal path. The first Fresnel zone is positioned so that energy leaving the transmitter and reflecting anywhere off the surface of the first zone will travel along a path that is exactly one-half wavelength longer than the energy that traverses the direct path, see Figure 2. An additional delay of one-half wavelength is experienced at the reflection point. Theoretically then, energy arriving at the receiver from these two paths will be in phase and will add vectorially to produce a resultant signal strength 6dB higher than the signal strength of the direct path alone. Path clearances over actual reflective points that are equal to the first Fresnel zone will therefore result in a received signal level of up to 6dB above the free space level, depending upon the reflection coefficient of the reflecting surface.

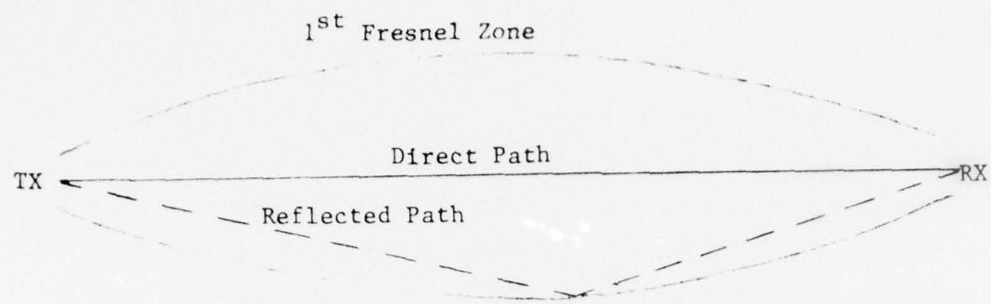


Figure 2. First Fresnel Zone

2.1.1.1 The second Fresnel zone is positioned so that energy reflecting from any point on its surface will travel along a path that is exactly one wavelength longer than the direct path. Because of the 180° phase delay at the reflection point, the direct and reflected signals will arrive out of phase at the receiver and when added vectorially, will cancel. In actual practice, the amount of signal depression will depend upon the *reflection coefficient* of the surface.

2.1.1.2 Succeeding Fresnel zones are spaced at one-half wavelength intervals. In general, the rule is that energy reflected from odd Fresnel zones will be in phase with the direct signal and will add to it, and energy reflected from even Fresnel zones will be out of phase with the direct signal and will subtract from it.

2.1.1.3 The first Fresnel zone radius for any point in the path can be calculated from the following formula:

$$F_1 = 72.1 \sqrt{\frac{d_1 d_2}{fD}} \qquad (1)$$

where F = First Fresnel zone radius, in feet.

D = Path length, in miles.

d_1 = Distance from one end of path to reflection point, in miles.

$d_2 = D - d_1$

f = Frequency in GHz.

If the value of the first Fresnel zone radius is known, the value for the nth zone, where n is the Fresnel zone number, can be calculated from the following formula.

$$Fn = F\sqrt{n} \qquad (2)$$

2.1.1.4 Reflection fading from ground or water surfaces, or ground or elevated atmospheric layers, can produce a rolling pattern on an AGC chart recording, as shown by Figure 3. This type of fading is the result of alternate odd and even Fresnel zone clearances occurring over the reflection point and can be caused by an atmospheric layer rising through the path, or changes in the refractive index causing the path clearance to change with time. This type of fading can cause the received signal level to be 40dB, or more, below the free space signal level because of the phase cancellation between the direct and reflected paths. If the path happens to provide an even Fresnel zone clearance over a reflective point during normal propagation conditions, the received signal level on the path will be depressed a high percentage of the time. The amount of the signal depression is dependent upon the reflection coefficient of the reflecting surface.

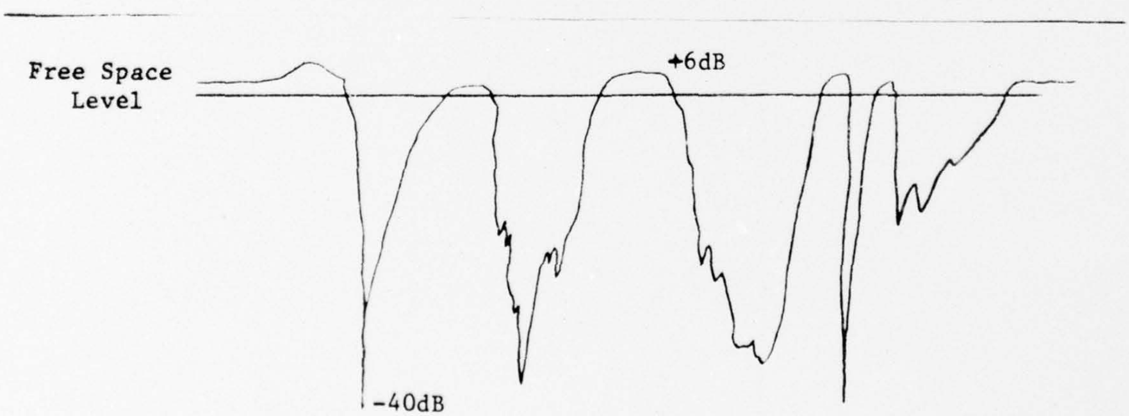


Figure 3. Typical AGC recording of reflection type fading

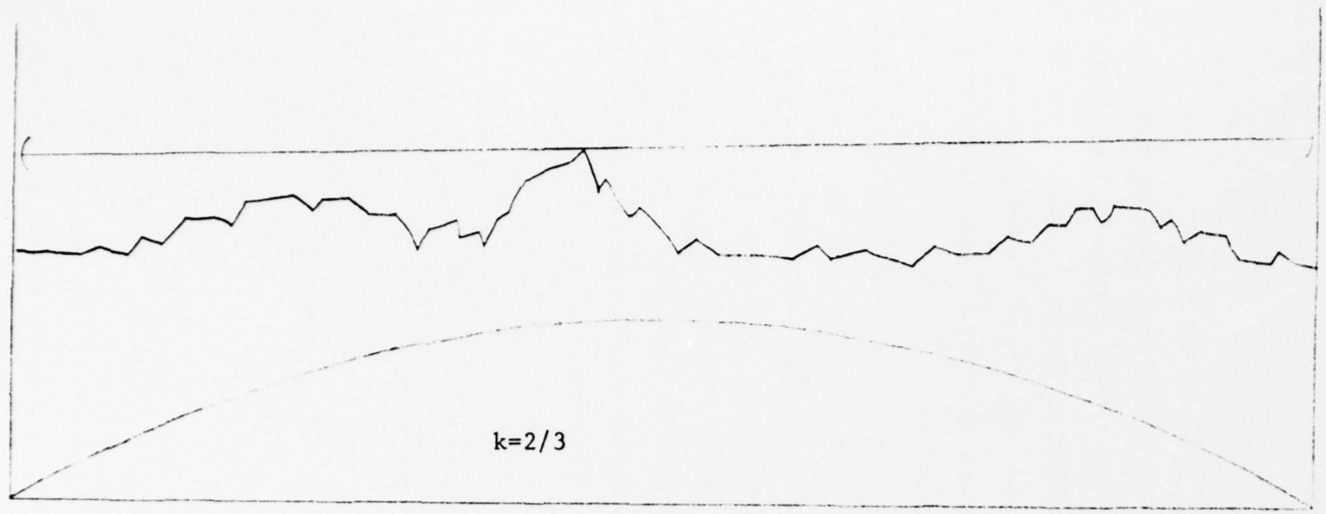


Figure 4. Obstructed Path

2.2 Obstructions. Fading due to an obstruction, shown by Figure 4, is a function of path clearance. Clearance just equal to the first Fresnel zone will result in an RSL above the free space level. If no reflections are present and the signal is not subject to diffraction, the RSL will equal free space when the path clearance is equal to 0.71 of the first Fresnel zone. Grazing clearance, as shown by Figure 4, will result in an RSL approximately 8 to 20 dB below free space. A typical AGC recording illustrating obstruction fading may look like Figure 5.

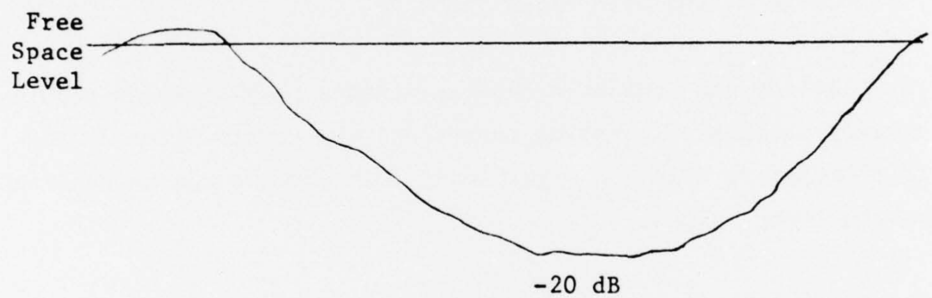


Figure 5. Typical AGC recording of obstruction type fading

2.2.1 Because of the fade margins in use today (typically 40dB), outages attributed to obstruction fading can be practically eliminated through proper path engineering.

3.0 PATH TESTING

3.1 Purpose. The purpose of path testing is to provide information on path characteristics that cannot be calculated or detected by inspection of the path. Path testing will confirm the workability of a microwave path and find the optimum antenna heights to minimize degradation caused by:

a. Undesired reflected signals, or

b. Blockage of the main signal path.

3.1.1 Path testing can prevent excessive antenna heights which result in unnecessary loading of existing towers and the construction of new towers of unnecessary size. A significant cost savings can be realized by minimizing tower heights.

3.2 Preliminary Analysis. Preliminary microwave path analysis is a necessary and useful tool; it must be recognized however, that regardless of the amount of effort expended upon theoretical analyses, site and path surveys, and optical sitings and verifications, four basic questions concerning the microwave path are left unanswered.

a. How many reflective areas are contained in the path?

b. Where are the reflective areas located?

c. How severe are the reflections?

d. Are obstructions as indicated on the preliminary path profile?

Path testing provides the answers to these questions.

3.3 When to Test. At this time, path testing is recommended for:

a. All new mainline DCS microwave paths, with the possible exception of short paths over which the path clearance is known for a k of up to infinity.

b. All other new paths that require the same high degree of reliability as the DCS, and

c. Existing paths that exhibit fading characteristics which can be attributed to path difficulties.

3.3.1 After AFCS has gained field experience in path testing, more definitive criteria on when to test will be established.

4.0 BRIEF DESCRIPTION OF TECHNIQUES

4.1 CW Technique. The CW technique for path testing involves the transmission of a single frequency signal and the recording of the corresponding received signal level (RSL). This is done while varying the transmit and receive antenna heights. Alternate reinforcement and cancellation of the direct signal by the reflected signal produces an interference pattern which appears as changes in RSL as shown by Figure 6. It is the interference pattern, represented by the signal strength variation for various combinations of antenna heights, that enables the test engineer to determine the optimum antenna height. Analysis of the interference pattern and the path profile locates the obstruction and/or reflection points in the path. AT&T Long Lines is the prime user of this technique.

4.1.1 Equipment. The normal complement of equipment consists of the following:

a. Transmit and receive RF heads, 1 ea.

b. Temporary towers and tracks, 2 ea, 300 feet ea.

c. Antenna carriage, 2 ea.

d. Winch, 2 ea.

e. Parabolic antenna, 2 ea.

f. Broadband sampling voltmeter, 1 ea.

g. Mobile VHF radio, 2 ea.

h. Transportable power units, 4 ea.

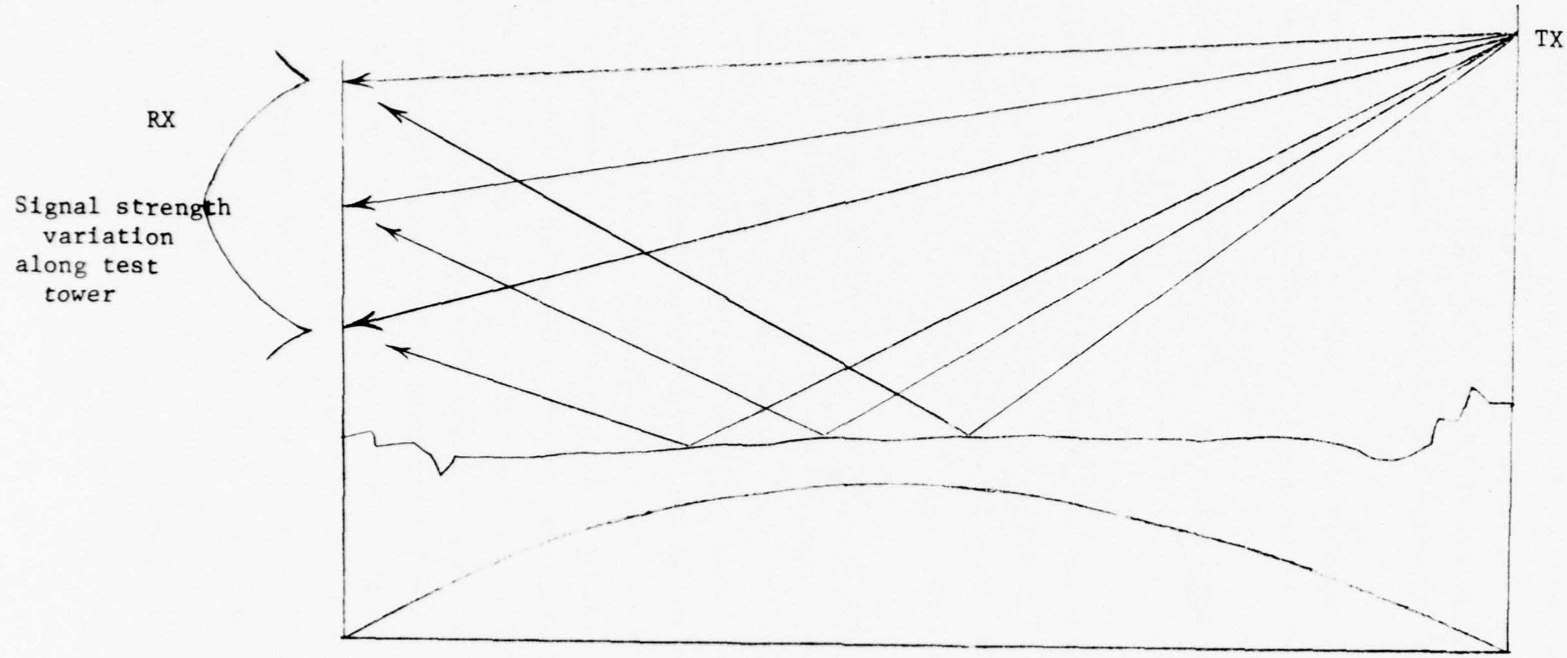


Figure 6. Interference pattern

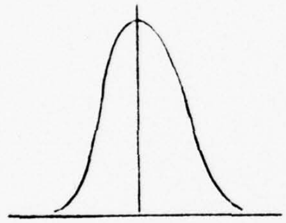
4.1.1.1 The RF heads are mounted directly on the carriages behind the parabolic antennas and travel up and down the towers with the antennas. At the receive site, the 70 MHz IF is brought down the tower by an RF cable and is fed directly to the broadband voltmeter.

4.1.1.2 The antenna carriages contain servo motors which permit the remote control of the antenna tilt and azimuth positioning.

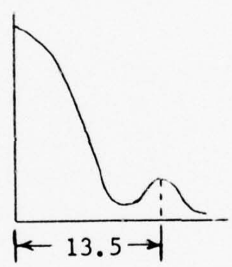
4.1.1.3 Winches are calibrated in 0.1 foot increments to permit accurate height resolution.

4.1.1.4 One power unit at each site is used to supply power solely to the electronic equipment. The second power unit at each site is used to drive the winch that controls movement of the antenna carriage up and down the tower.

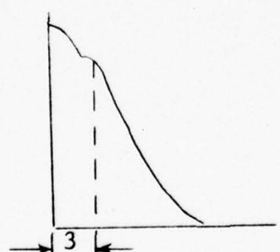
4.2 Digital Technique. In the early 1950's, O.E. DeLange of the Bell Laboratories used short microwave pulses as a means of studying microwave propagation. The basic theory behind the pulse method was that if there was more than one path, and if the pulses were sufficiently short in comparison to the path length differences involved, then separate pulses would be received for each path. DeLange was able to observe multipath fading by this method and record secondary path length differences ranging from a fraction of a foot up to about seven feet. The Institute for Telecommunication Sciences (ITS) acquired a sophisticated version of this equipment from the Bell Labs in about 1972. Since that time, the ITS has made extensive modifications to increase the measurement capabilities. The data obtained by the present day equipment appears as an oscilloscope display and is shown by Figure 7. If no multipath components are present in the transmission path, the reference pulse, which represents the direct path, will return - smoothly to the base line as shown by Figure 7.a. If reflections are present, they will appear as pertubations either on the base line, Figure 7.b., or on the reference pulse, Figure 7.c. The position of the pertu-



a. Reference pulse



b. Reflected pulse delayed 13.5 nanoseconds



c, Reflected pulse delayed 3 nanoseconds

Figure 7. Digital method output display

bation is dependent upon the time delay, or relative path length difference between the direct and reflected path. If there are several pertubations varying randomly with time, then atmospheric multipath exists. Ground reflected components appear as relatively stable peaks. High magnitude components indicate strong reflections and long time delays indicate large deviations from the direct path.

5.0 TEST TECHNIQUES

5.1 General. To locate microwave antennas at the optimum heights for system performance, something must be known about the relative strength of the received signal level at various antenna positions. This information is gathered during path testing and is plotted as a height-gain curve. Analysis of the curve will locate the reflection and obstruction points and indicate the degree of interference with the direct signal path.

5.2 CW Technique. The CW technique uses single frequency transmission and produces the height-gain curve in a simple and direct manner. The received signal level is recorded while the transmit and/or receive antenna heights are varied. Three types of tests are normally performed on each path.

a. Test A, transmit and receive antennas moved up the towers simultaneously.

b. Test B, transmit antenna moved, receive antenna held stationary.

c. Test C, transmit antenna held stationary, receive antenna moved.

The tests will be conducted so that the best and worst combinations of antenna heights are included in the height-gain curves. This can be accomplished by performing an offset A test, i.e. an A test that begins with the transmit and receive antennas at different heights.

5.2.1 Propagation Conditions. It is not necessary to know the exact value of the effective earth radius factor (k) during the testing period. This value is assumed to be 4/3. (A k of 4/3 is the so called standard value for dry inland climates and it is the value that can be expected most often, at least during daytime hours.) Analysis of the test results

will accurately locate reflection and obstruction points despite the exact value of k. Slight errors in determination of obstruction heights can occur if the actual k value is not 4/3, however this value is still much more accurate than existing maps. The important consideration is that k remain constant throughout the test period.

5.2.1.1 Path testing usually does not start until about 2 hours after sunrise and continues until about 2 hours before sunset; this is the period of the day when propagation conditions are least likely to be changing. In lieu of making a determination of k, temperature readings are recorded at the beginning of each test. A rapid change in temperature could indicate an approaching weather front and a change in propagation conditions. If weather changes are observed, testing is temporarily halted until conditions stabilize. If weather conditions do not stabilize, test results for that day are discarded and testing starts over on the following day.

5.2.1.2 It is necessary to have a stable k during the entire testing period to permit accurate location of reflection and obstruction points. Significant changes in k will cause the apparent location of these points to vary. If this goes unnoticed, permanent antenna heights that provide for much less than optimum performance may be chosen.

5.2.1.3 A common test is repeated several times throughout the day as a further check on the stability of k. If k has not changed, the height-gain curves for these tests will be identical. A change in k causes free space crossover points to be different because of different path clearances for various k values. If large changes in k are observed, test results for that day are invalid and retesting will be necessary.

5.2.2 Reflective Path Analysis. As an example, the profile in Figure 8 is of a 30 mile path over highly reflective terrain. No trees exist which could break up or block possible reflections.

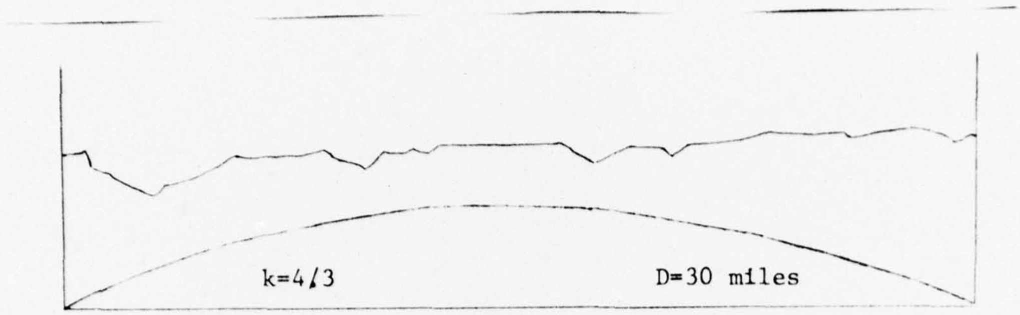


Figure 8. Path profile

5.2.2.1 Height-gain curves made during the A, B, and C tests are shown in Figure 9. These curves were made by recording the receive IF signal level, which is directly proportional to the RF signal level, while incrementing the transmit and receive antenna heights. The antenna heights were changed in five foot increments. Near the null points in each curve, the antenna heights were changed in one foot, or smaller, increments.

5.2.2.1.1 During the A test, the path clearance over the reflection point is directly proportional to the antenna heights. The path clearance passes through alternate odd and even Fresnel zone clearances as the antenna heights are changed thus causing the reflected signal to alternately reinforce and cancel the direct signal. The spacing between the two nulls of the A test shown in Figure 9, 105 and 164 feet respectively, is 59 feet. In Fresnel zone radii tables for a 4 GHz, 30 mile path, this corresponds to the spacing between the 2nd and 4th Fresnel zone at a distance of 15 miles from one end. Assuming that the first null in the height-gain curve is caused by the 2nd zone, the clearance over the reflection point should be 140 feet.

5.2.2.2 The transmit and receive antenna heights corresponding to the first null point for the A test (105 and 135 feet) are layed out on the path profile and connected together by a straight line, see Figure 10. The same is done for the first null points for the B and C tests.

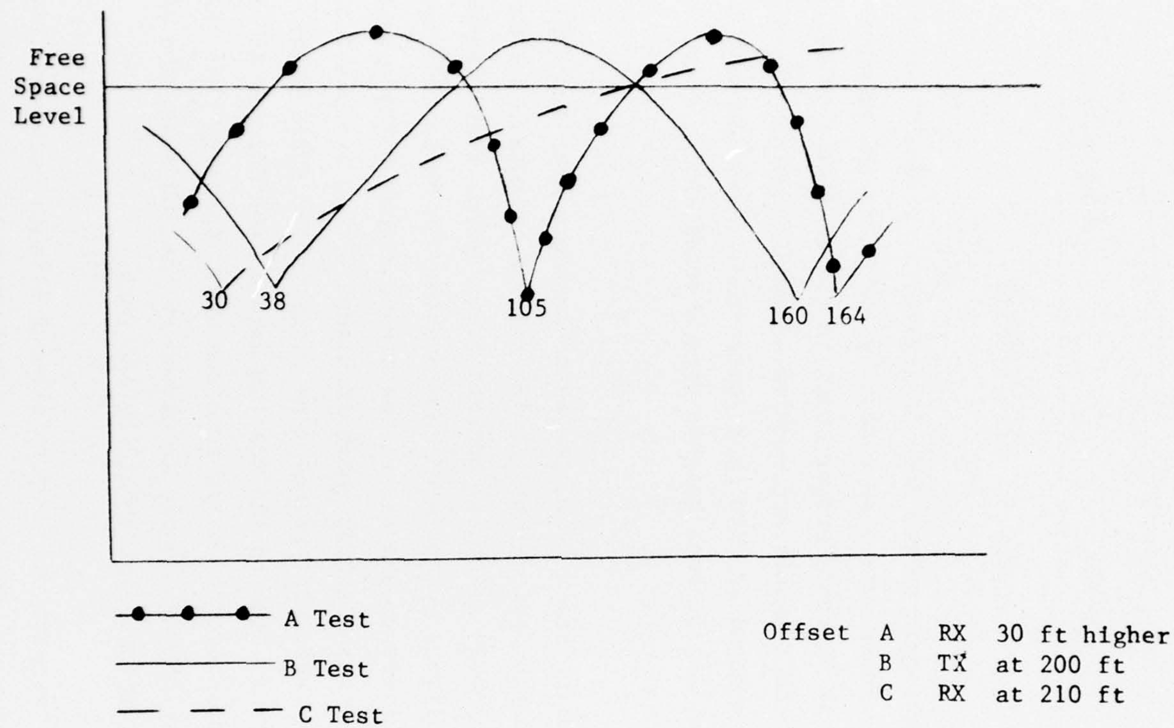


Figure 9. Height-gain curves

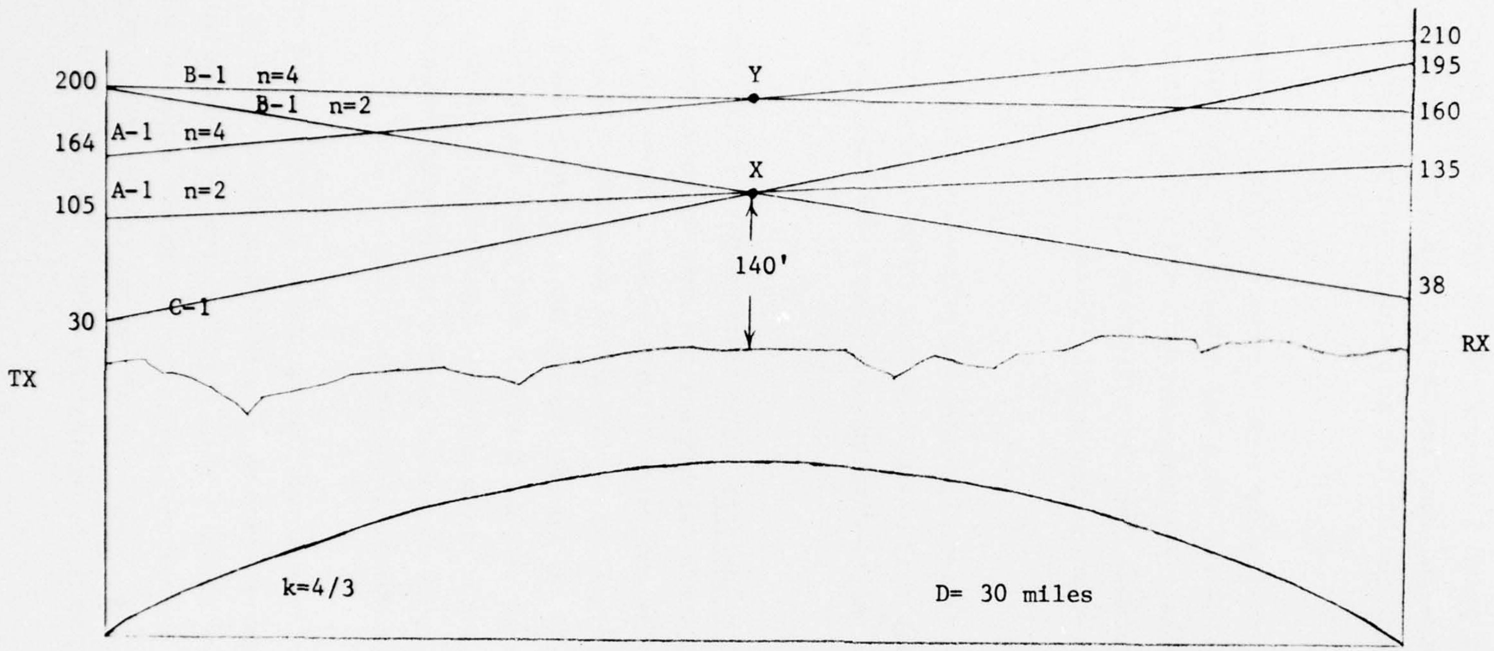


Figure 10. Reflective path profile

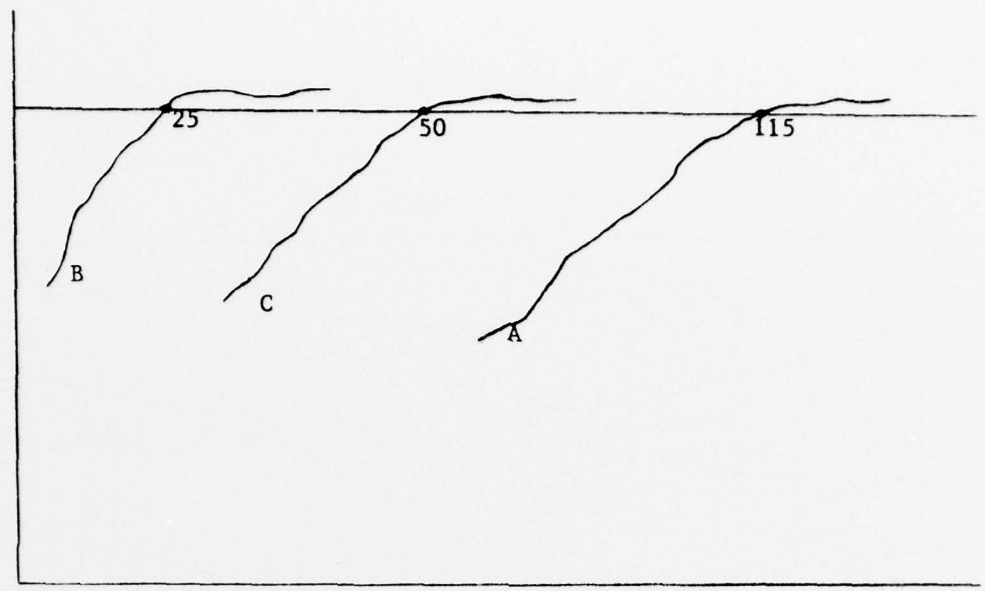
The lines intersect at point X, which is above the reflection point. The path clearance at point X is equal to 140 feet, which corresponds to the 2nd Fresnel zone and verifies the profile. Had the profile not shown a clearance equal to 140 feet at point X, the profile would have been corrected.

5.2.2.3 Next, the transmit and receive antenna heights corresponding to the second null point for the A and B tests are layed out and connected together. These lines intersect at point Y and indicate the 4th Fresnel zone clearance over the reflection point. The 4th Fresnel zone radius is 200 feet which corresponds to the path clearance over point Y.

5.2.2.4 In actual practice, locating the reflection point will seldom be this easy. A great many paths have two, three or more reflections which complicate the height-gain curve and make the analysis much more difficult.

5.2.3 Obstructed Path Analysis. The tests used to locate obstruction points and determine their heights are the same as those used to locate reflection points. The analysis of these tests is based on the fact that the free space signal level is reached when the clearance over an obstruction is 0.71 of the 1st Fresnel zone on paths where neither diffraction nor reflection play a significant role, and 0.55 of the 1st Fresnel zone on paths where they are significant. Precise determination of the free space crossover points is therefore necessary to accurately locate the obstruction points.

5.2.3.1 Height-gain curves made during the A, B, and C tests are shown in Figure 11. The curves were made by recording the receive IF signal level while incrementing the transmit and/or receive antenna heights. The antenna heights corresponding to the free space crossover point for the A test, 115 feet, are layed off on the path profile, Figure 12, and connected together by a straight line. The same is done for



Antenna Height
B - TX at 180 ft
C - RX at 210 ft

Free Space Crossover Points			
Test	A	B	C
TX	115	180	50
RX	115	25	210

Figure 11. Height-gain Curve

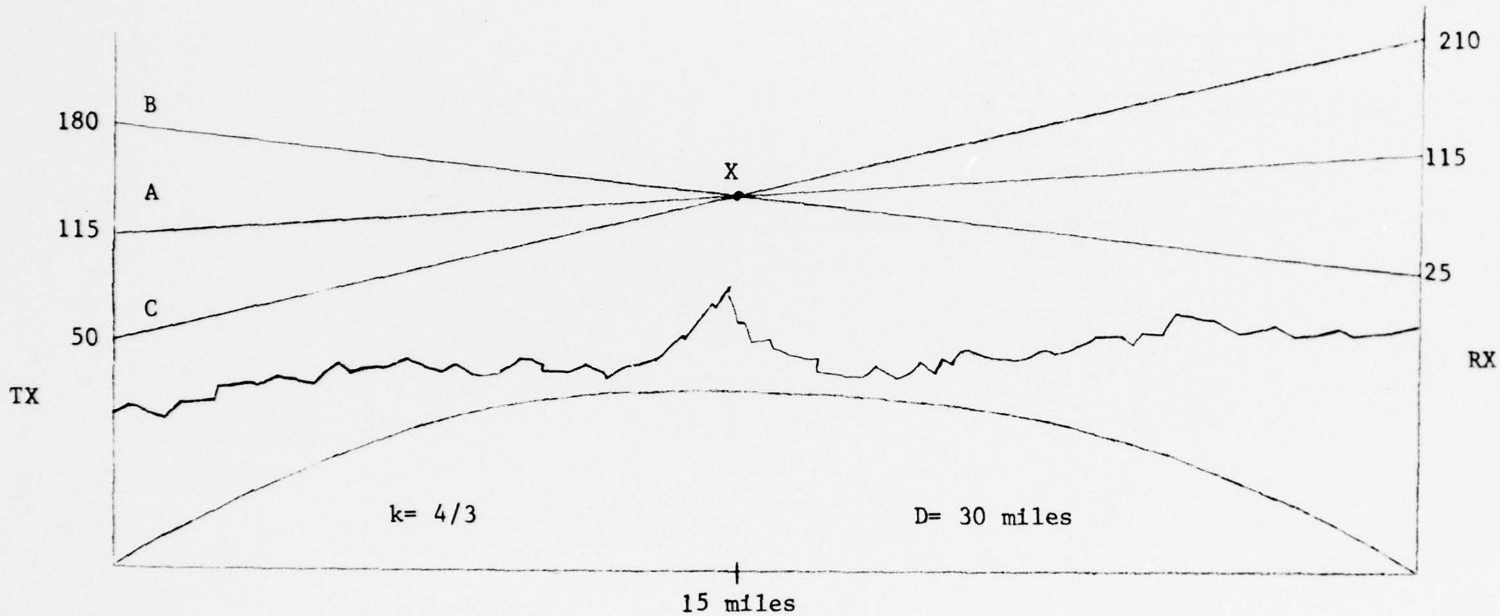


Figure 12. Obstructed path profile

the B and C tests. The lines intersect at point X. The height-gain curves in Figure 11 are recognized as being caused by an obstruction; they do not have the variance about the free space level that is characteristic of a diffraction shot. The height of the obstruction is therefore located 0.71 of the 1st Fresnel zone radius below point X, or 70 feet in a 4 GHz shot. This accurately determines the obstruction height.

5.2.3.2 Locating the obstruction point and determining its height in a diffraction shot is done in a similar way. The only difference is that the obstruction height is 0.55 of the 1st Fresnel zone below the intersection point, X.

5.2.3.3 In actual practice, a path may have some combination of diffractions, obstructions and/or reflections. Analysis of these paths is much more detailed and should only be done by experienced personnel.

5.3 Digital Technique. In the digital technique, a pseudo-random keystream is biphase modulated and transmitted for comparison with a similar keystream that is produced within the receiver. The keystream is 511 bits long and is clocked at 150 MHz in the transmitter and slightly less than 150 MHz in the receiver. The two signals are compared within the receiver by a correlation process, which is useful for comparing signals and indicates the similarity between one signal and a time delayed version of that signal. The output of the correlator is displayed on an oscilloscope. Secondary transmission paths appear as pulses occuring later in time than the reference pulse, which represents the direct path, see Figure 7.

5.3.1 Reflective Path Analysis. The digital technique enables the test engineer to probe the transmission path from fixed antenna positions. The secondary path in the profile shown by Figure 11 has a time delay of approximately 0.25 nanoseconds with the TX and RX antennas

at 105 and 135 feet respectively. This delay is too small to be displayed as a separate pulse on the oscilloscope; but, because the path clearance is equal to the 2nd Fresnel zone, the reference pulse will be below the free space value. In this case the test engineer would probably want to increase the antenna heights while observing the reference pulse. An increase above the free space level would indicate that an odd Fresnel zone reflection was present, however the location of the reflection point would still be unknown. If the antenna heights were increased to about 400 feet, the time delay of the reflected path would be near 2 nanoseconds and would be displayed as shown in Figure 13.

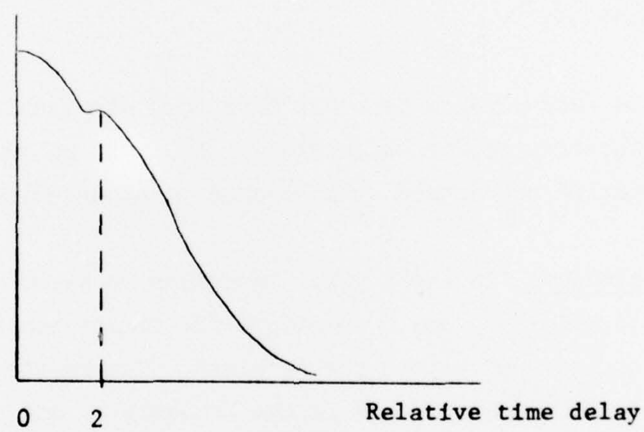


Figure 13. Oscilloscope display

5.3.1.1 The reflection ellipse is then drawn directly on the path profile. This ellipse is representative of a surface positioned such that any secondary path reflecting from it is delayed by 2 nanoseconds. The reflection point is located at the point where the reflection ellipse is tangent to the surface as shown by Figure 14.

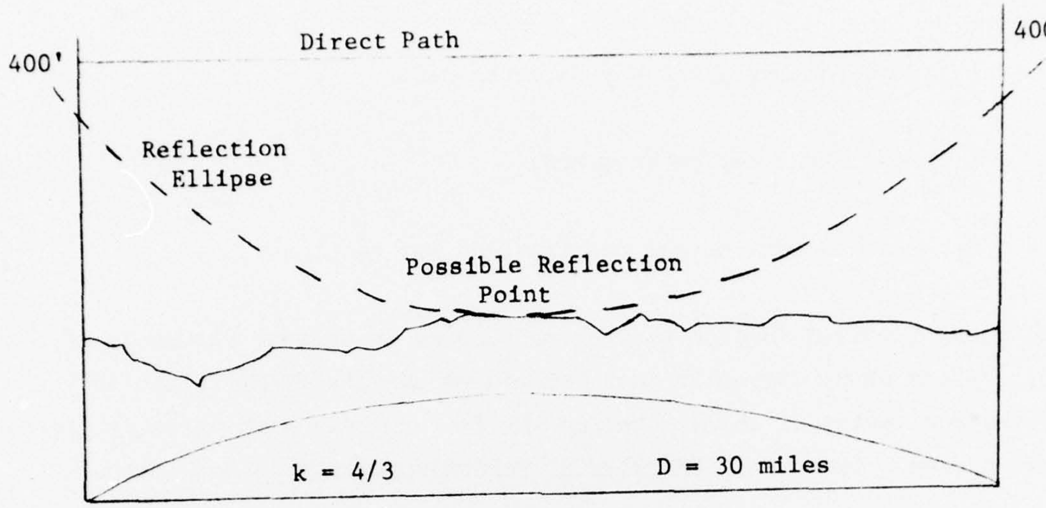


Figure 14. Reflective path profile

5.3.1.2 The digital technique does not work well on this path because of the small time delays involved with lower order Fresnel zone reflections. If the reflections are strong enough, they will appear as amplitude changes in the reference pulse. This, however, tells nothing about the location of the reflection point. The CW technique treats this path, and similar lower order Fresnel zone clearance paths, with routine ease.

5.3.2 Obstructed Path Analysis. The digital technique is not used to identify obstruction points and obstruction heights.

5.4 Faulty Test Technique. It must be strongly emphasized that path testing should only be attempted by EXPERIENCED PERSONNEL.

5.4.1 Improper test technique and analysis are worse than no testing at all because of the misplaced confidence in the fact that the route has been tested. In addition, the following can result.

a. The time, money and effort spent testing the path may be wasted.

b. Satisfactory paths may be abandoned.

c. Poor paths may be accepted.

d. Poor antenna height combinations may be chosen.

The money involved in path testing may amount to several thousands of dollars per path. Improper test procedures can therefore result in tremendous wastes of dollars and/or the failure of a high priority microwave system. The use of EXPERIENCED PERSONNEL cannot be overstated.

6.0 CONCLUSIONS

6.1 Path testing is often the only way in which the propagation characteristics of a path can be determined with the required degree of accuracy. Even if maps are available, serious errors in elevation are common enough to be of concern. Furthermore, severe reflections occur frequently, even on paths that appear to be fairly well wooded. These considerations make it necessary to test a large portion of the paths selected, at least on the major routes where a high degree of reliability is required. To fully realize the advantages of path testing, those personnel conducting the tests must be experienced.

6.2 AFCS will acquire an organic path test facility in the near future. To realize the greatest benefit from this facility, the 1839 EIG (AFCS) will assign a dedicated team to conduct path tests. In addition to performing tests for Air Force agencies, AFCS path testing services will be made available to other agencies within the federal government.

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